A Molecular Clock Architecture for Deep Space Inter-SmallSat Radio Occultation

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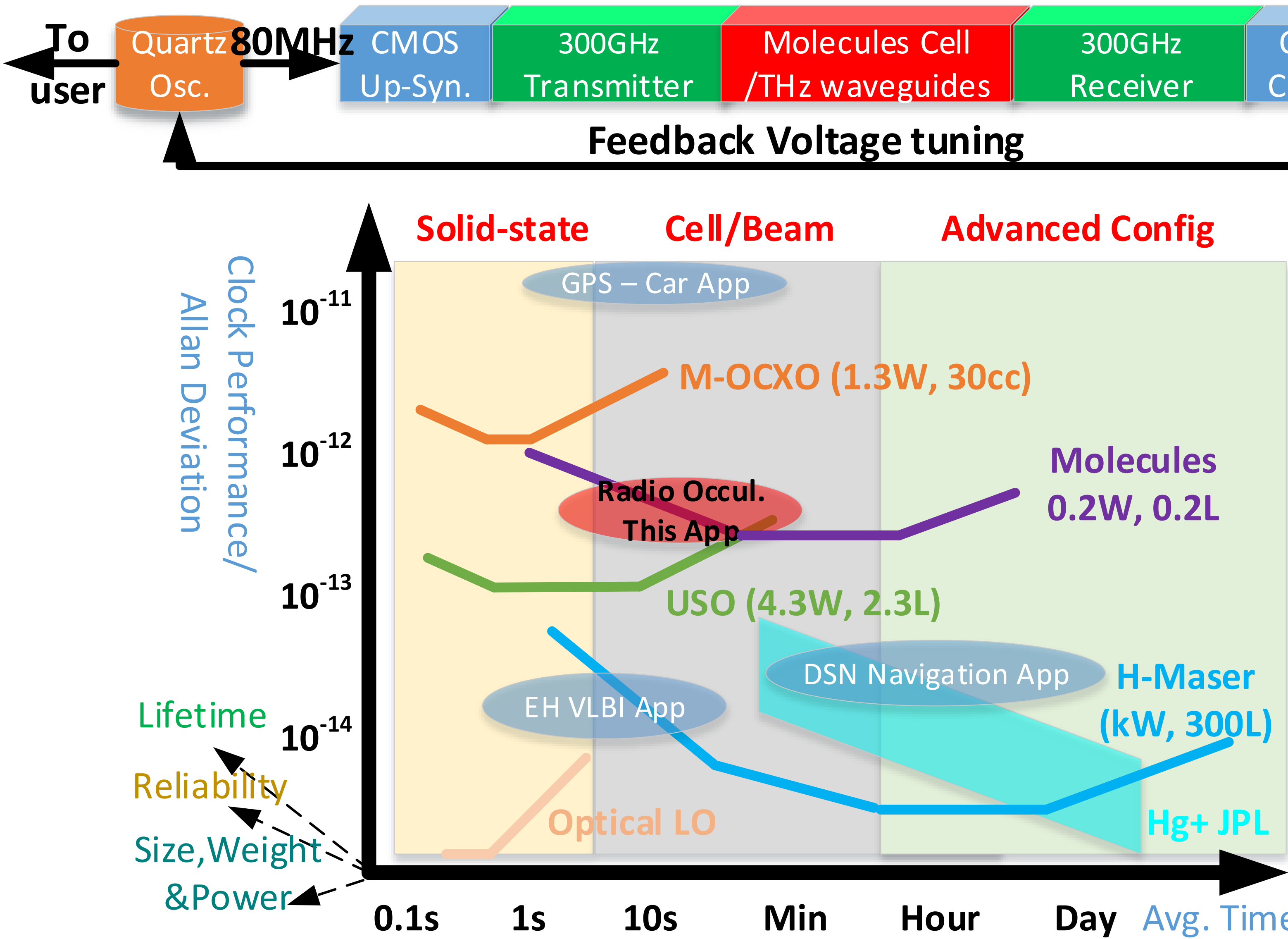
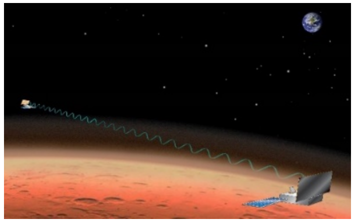
Application of THz-Molecular Clock



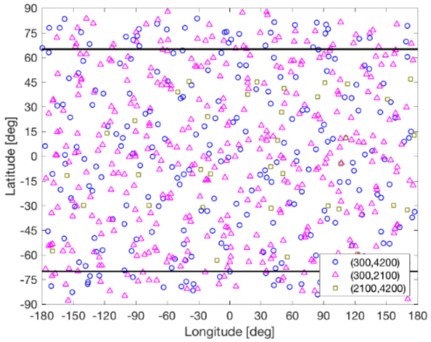
Deep Space One-way Radio Occultation with Global SmallSats Constellation*

- **Science**
  - Intersatellite radio occultations from a smallsat constellation around Mars or Venus provide high vertical resolution measurements of **temperature and pressure** (in neutral atmosphere) and **electron density** (in ionosphere) with high spatial and temporal coverages that address high-priority MEPAG and VEXAG objectives.
  - Two-way does not need very good clock, but adds system complexity.
  - One-way need on-board clocks with good short-term stability.



- **Specific science due to clock technology reality**
  - Mars lower altitude atmosphere
    - MEPAG goal II, Mars climate history
      - A1.1: Measure the state and variability of the lower atmosphere from turbulent scales to global scales (High Priority).
    - MEPAG goal IV, Prepare for Human Exploration
      - B1.2: monitor surface pressure and near surface meteorology (High Priority)
      - B1.3: Measure temperature and aerosol under dusty conditions.
  - Planets with thick atmosphere, i.e. Venus, Titan

RO coverage over 7 days from a constellation of 3

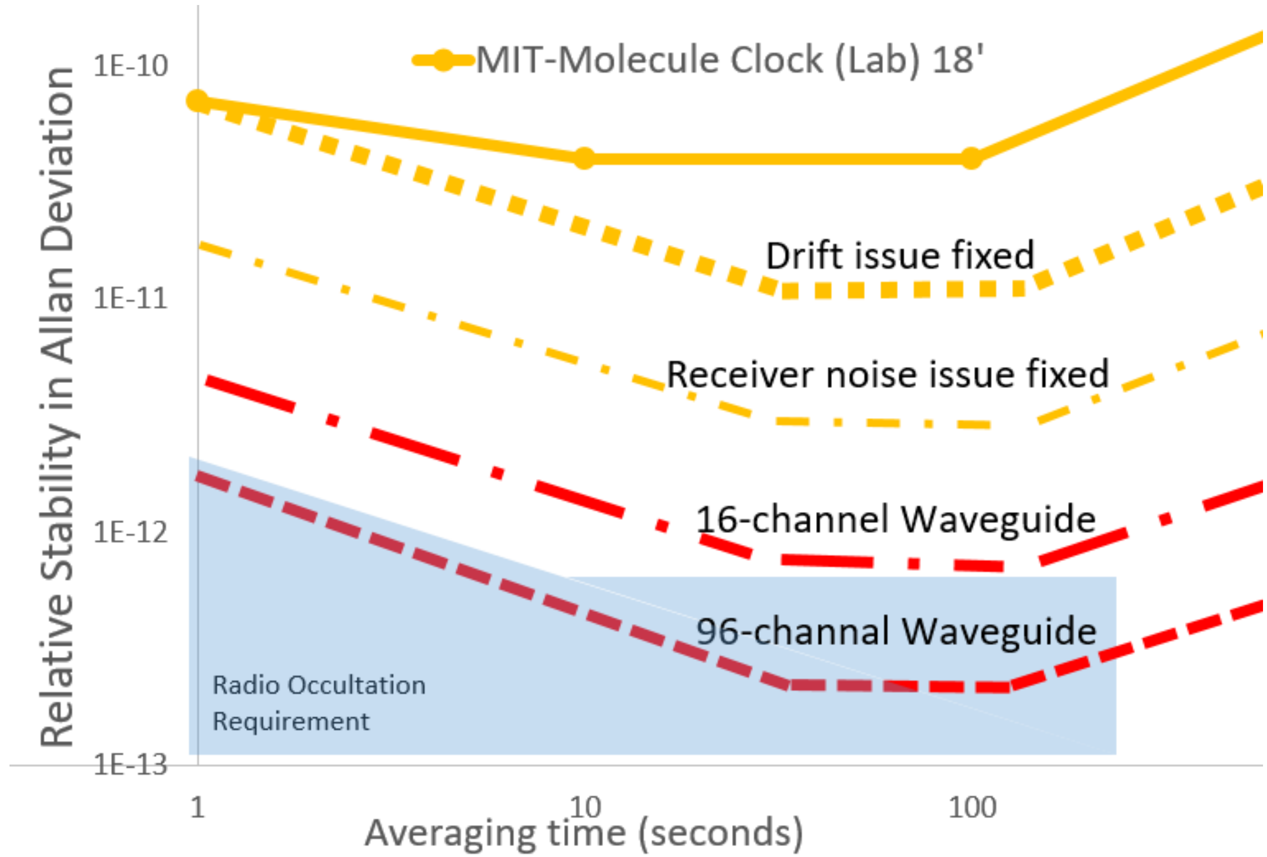


Complex Trade-space

- **Requirements on on-board clocks**
  - Stability of 10^{-13} at 100s
    - → Need assist from atom/molecular
  - Size, Weight and Power constraints: <<1L, <<1.3kg, <<10W.
    - → Need Integrated technology in electronics, mechanics and photonics.
  - Technology with inherent merits of long lifetime, high reliability, radiation-hardened, low environmental sensitivities.
    - → Need simple architecture and leverage from proven technology/components, better COTS

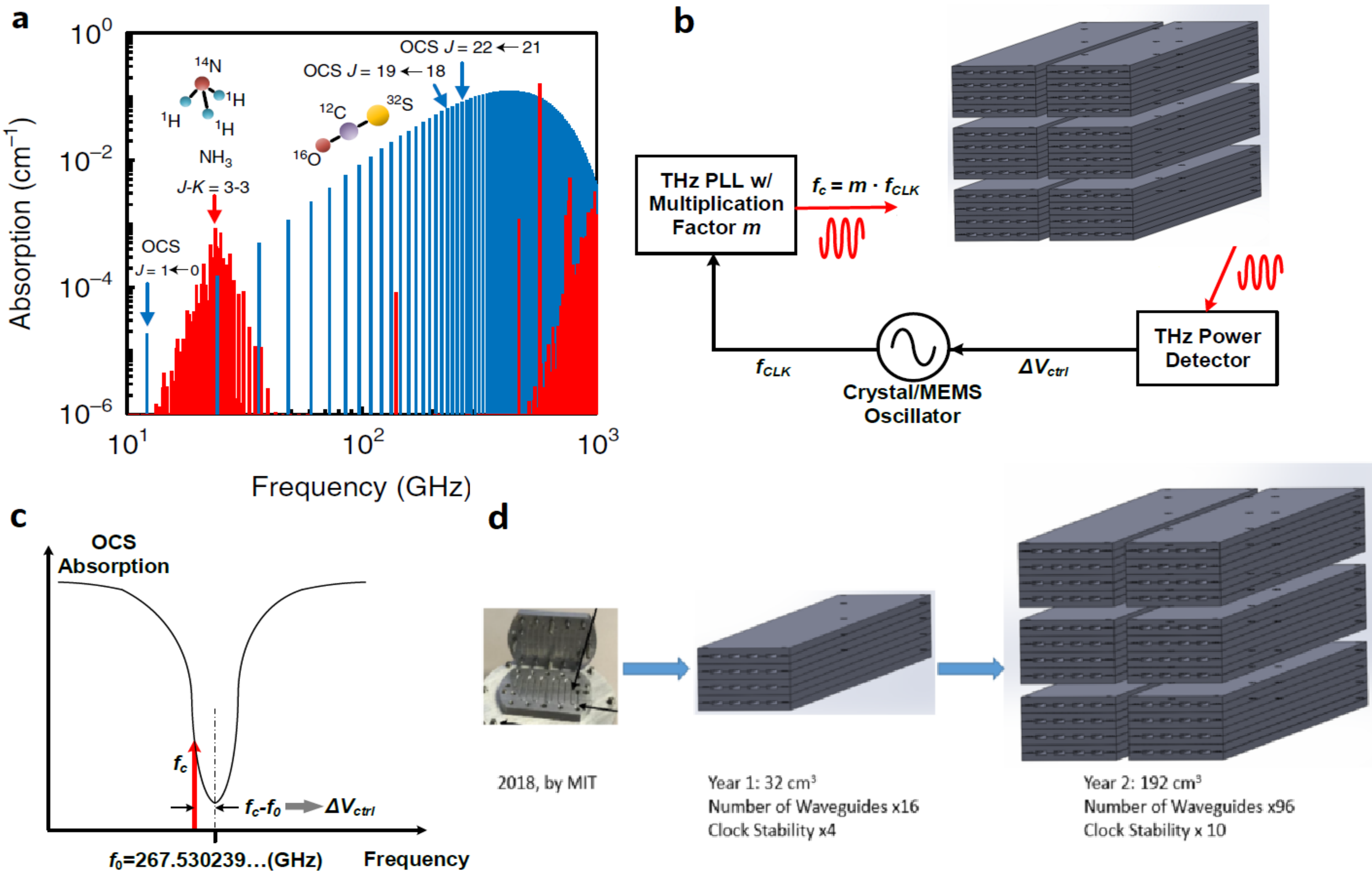
* http://www.lcpm12.org/wp-content/uploads/2017/08/0910-0930-Williamson.pdf, Williamson/Mannucci/Ao

Technical Approach



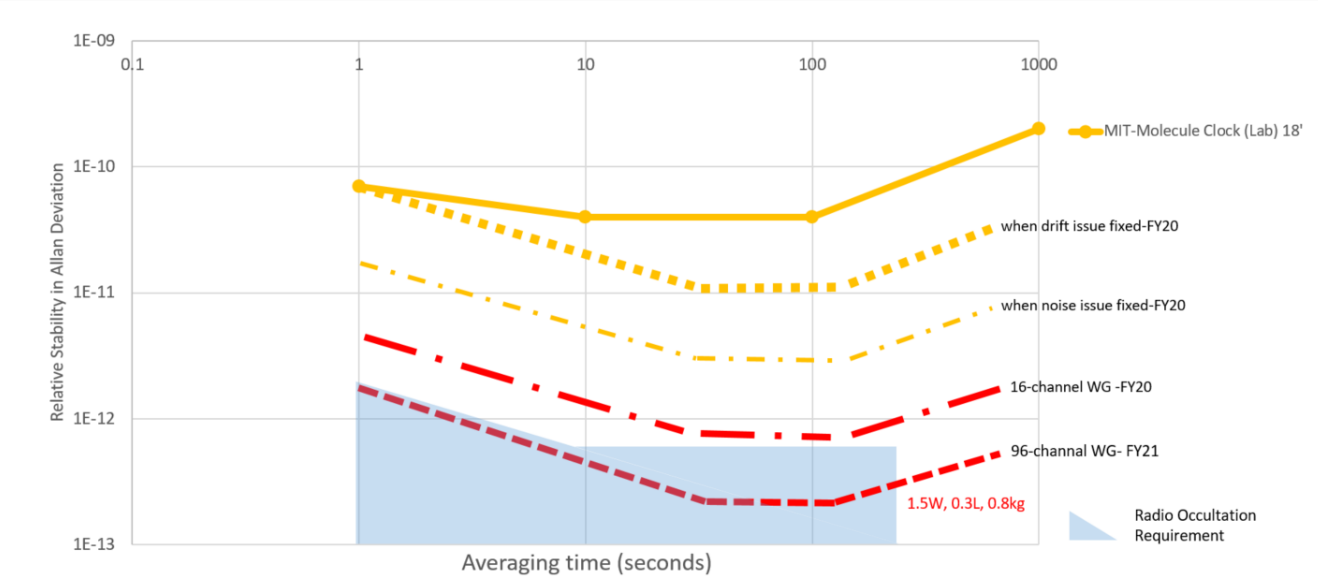
- **Key issue 1**: CMOS Receiver Noise: 500pW/√Hz --> 30 pW/√Hz (low risk)
- **Key issue 2**: Drift caused by vacuum and cavity pulling: UHV high temperature bakeout, cavity-mode locking (low risk)
- **Key issue 3**: Not enough participating molecules (low SNR): Single channel to multi-channel scalability (high risk)

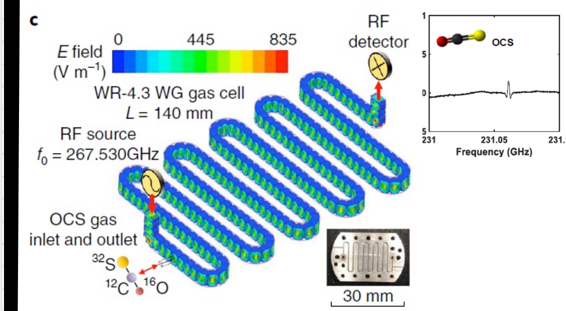
Backup slides



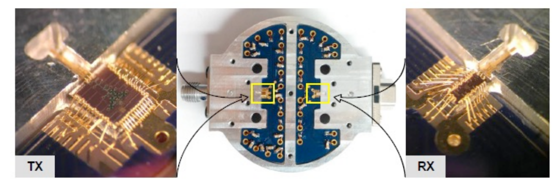
a
b
c
d
Absorption (cm^{-1})
Frequency (GHz)
OCS J = 22 ← 21
OCS J = 19 ← 18
^{14}N
^{1}H
NH$_3$
J-K = 3-3
^{12}C
^{32}S
^{16}O
OCS
J = 1←0
THz PLL w/ Multiplication Factor m
$f_c = m \cdot f_{CLK}$
THz Power Detector
f_{CLK}
ΔV_{ctrl}
Crystal/MEMS Oscillator
OCS Absorption
f_c
f_c-f_0
f_0=267.530239…(GHz)
Frequency
2018, by MIT
Year 1: 32 cm³
Number of Waveguides x16
Clock Stability x4
Year 2: 192 cm³
Number of Waveguides x96
Clock Stability x 10

Concept: Molecular-assisted miniaturized oven-controlled crystal oscillator

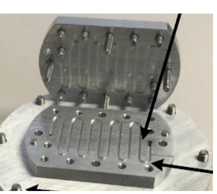


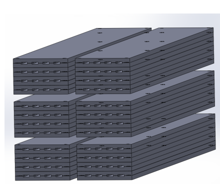


*C. Wang et al., Nature Electronics 1, 421 (2018)



Key 1: Scalability (JPL-MIT)





“Snake”* “Honey-Comb”**

Key 2: Receiver Noise MIT-JPL

CMOS Receiver Noise: 500pW/√Hz --> 30 pW/√Hz considered low risk

Key 3: Drift Fix JPL-MIT

- UHV high bakeout WG
- Cavity Mode locking